Implementation of Self-Consolidating Concrete (SCC) for Prestressed Concrete Girders

Introduction

Self-Consolidating Concrete (SCC) is a relatively recent technological development in concrete construction. Availability of a new generation of chemical admixtures has made it possible for freshly mixed concrete to flow freely and to consolidate under its own weight without segregation. Therefore, SCC allows rapid and easy placement without vibration in slender members, deep and thin sections with congestion of reinforcement. It increases the speed of construction, enhances the quality of product, reduces the labor cost, and improves the construction productivity.

In June 2003, the NCDOT, NCSU, and Georgia/Carolinas PCI jointly sponsored a workshop on SCC. More than 60 NCDOT engineers attended the workshop. The participants in that highly successful event reviewed the results of recent advances of SCC and witnessed successful demonstrations of the superior performance of the material. It is timely for the NCDOT to explore the use of this high performance material and take advantage of all its potential benefits. Prestressed concrete industry is also prepared to consider appropriate use of this new technology. At least one prestressed concrete producer in NC has expressed interest in participating in this project and is willing to underwrite a portion of the project cost. A chemical admixtures manufacturer will also participate in this research partnership.

Problem Statement and Research Objectives

In contrast to the conventional concrete, SCC can be regarded as a specially designed concrete and its performance is highly dependent on the characteristics of its ingredient materials. In general, the behavior of SCC is quite similar to that of the conventional concrete such as compressive strength, shrinkage, and creep. However, SCC may have a lower modulus of elasticity because it contains more fine aggregates. This may affect the short-term and long-term deformation characteristics of prestressed concrete members. More research data is also needed for the bond strength between SCC and the prestressing strands. The potential impact of these properties of SCC on the behavior and design of prestressed concrete girders needs to be examined. In addition, the proper procedure for placing SCC in large-sized and long-span prestressed concrete girders in full-scale production needs to be demonstrated. Research is therefore needed to monitor the performance of SCC in a field production environment and to assess the behavior of prestressed SCC girders in order to obtain more research data from the field and to demonstrate the proper application of this new materials technology.

The objectives of this research are three-fold: (1) Determine and document the various properties of SCC used in the production of two prestressed SCC girders. (2) Monitor and document the actual production of two prestressed concrete girders using SCC. The girders will be selected from a NCDOT bridge project under contract. (3) Conduct static load tests of two

SCC girders and one non-SCC girder at the production site. The girders will be tested to full service load condition in order to validate their design and performance. Subject to satisfactory performance, the girders may be delivered and installed in the bridge for service as other non-SCC girders.

Research Approach

Prior of the production of the test girders, a literature search will be conducted to obtain as much relevant information as possible on the use of SCC in prestressed concrete girders. Contacts also will be made with both the industry and other state departments of transportation to determine any pertinent prior experience with SCC applications. In addition, the project team will review the proposed SCC mixture design with the girder producer and the Technical Advisory Committee for the project.

It is anticipated that three non-SCC girders and two SCC girders will be cast in the same production line. During the production of the SCC girders, the placement procedure for SCC will be observed and documented. Sample cylinders of SCC will be obtained for evaluation of the various short-term and long-term mechanical properties of the material. Some cylinders will be steam cured with the girders and some will be non-steam cured in order to obtain comparisons. The prestressing force will be monitored until after detensioning. The temperature record of the girders during the curing period will be maintained. Upon detensioning, the transfer length and end slip of prestressing strands will be measured. The transfer length will be measured by using either mechanical gages or embedded steel bars instrumented with strain gages so as to expedite production time.

After the girders are produced, the two SCC girders and one non-SCC girder will be tested at the prestressing plant up to the design criterion for service load (i.e., zero tension in the botton fiber). This will allow direct comparisons of the behaviors of the SCC girders and the non-SCC girder.

In addition, using separately cast SCC girder segments, pullout test of prestressing strands used as lifting loop anchored in SCC will be conducted to validate the load carrying capacity of the lifting loop. This test is of particular interest to the prestressing industry to satisfy the safety standards.

Research Tasks

To accomplished the objectives of this research, the following tasks will be pursued:

Task 1 — Conduct literature review to obtain information on the use of SCC in prestressing concrete applications. Survey the prestressed concrete industry and various state departments of transportation to identify any pertinent prior experience with SCC applications. This information will be summarized and documented for reference.

Task 2 — Review proposed SCC mixture design with the Technical Advisory Committee prior to casting of girders. If a demonstration of the proposed SCC mix is conducted, the mixture characteristics will be fully documented.

During casting of the SCC girders, observe and document the placement procedure as well as the procedure for roughening top flange surface required for composite action. Prepare sufficient number of test samples of the SCC used in the girders. Some of samples will be steam cured along side with the girders and other samples will be non-steam cured. Conduct short-term and long-term tests to determine the various properties of the SCC, and compare with similar properties of non-SCC where appropriate.

For fresh concrete, tests on SCC will include unit weight, slump flow, T_{20} test, J-Ring test, air content, U-box or L-box test and AVA test. Tests on non-SCC will include unit weight, slump, air content, and AVA test. These tests will be conducted in coordination with NCDOT Materials and Tests Unit.

For hardened concrete, tests on SCC will include compressive strength and elastic modulus at different ages, shrinkage and creep. Possible aggregate segregation and air void distribution will be examined by optical scanning. In addition, cursory comparative air permeability tests will be conducted on SCC and non-SCC slabs (2' x 2' x 4").

Task 3 — Monitor the prestressing force with load cells to determine the initial tension in the strands and the tension immediately after release of prestress. Measure the end slip and transfer length of strands at prestress release.

Task 4 — Conduct load tests of two prestressed SCC girders and one non-SCC girder up to the full design service load. Obtain the load-deformation data, and compare the performance of the girders with analytical predictions. Using separately cast SCC girder segments, conduct pullout tests of strands used as lifting loops to validate the load carrying capacity of such lifting loops cast in SCC.

Task 5 — Provide adequate visual documentation of the production and testing of the SCC and non-SCC girders including photographs and videotaping.

Task 6 — Prepare final report of the research project.

Schedule of Tasks

It is anticipated that this research project would require 8 months to complete, beginning on November 1, 2003. The following is the proposed schedule for the various research tasks:

Activity	Months from Initiation of Project 0 1 2 3 4 5 6 7 8
Task 1	xxxxxxx
Task 2	xxxxxxxxxxxxxxxxxxxxxxxxxxxxx
Task 3	xxxxxxx
Task 4	xxxxxxxxxxx
Task 5	xxxxxxxxxxx
Task 6	xxxxxxxx

Anticipated Benefits and Outcomes

SCC will greatly improve concrete placement and eliminate the problem of honeycomb in narrow concrete sections with congested reinforcement, resulting in higher quality and speed of construction, and more durable structures. The use of SCC will benefit NCDOT in overall cost savings because of improved quality and productivity of construction. The outcome of this research will be the valuable field data on material behavior and structural performance of SCC used in prestressed concrete products. These data will form the basis for developing guidelines with which NCDOT and the prestressed concrete industry can make effective use of SCC in concrete structures where high workability will reduce cost and improve the quality of construction.

Implementation and Technology Transfer

Upon completion of this research project, presentations will be made to the NCDOT engineers and the prestressed concrete industry to review the results of the test program. The research team will also review the various issues with respect to PSP with NCDOT Structures Design for future projects.

Staffing Plan

The proposed research will be conducted by Dr. Paul Zia as PI and Mr. Roberto A. Nunez as Co-PI. They will be assisted by a half-time graduate research assistant and one or two undergraduate research assistants employed on an hourly basis as needed.

Participation by Industry

S & G Prestress Company of Wilmington, N. C., which is the subcontractor for producing the prestressed concrete AASHTO girders for the Craven-Pamlico Counties Bridge over Upper Broad Creek (NCDOT Project 8.1170903), has requested to use SCC for casting the girders at no additional cost to the project (see Attachment). S & G will also provide space, facilities, and support personnel for the testing of two girders at its plant. Its support to this implementation project represents an in-kind contribution of $15,000 to $20,000. In addition, the admixture producer (W. R. Grace) will provide its technical assistance in the design and production of SCC at S & G plant. W. R. Grace will also furnish free of charge the admixtures necessary for the production of the two demonstration girders. Letters from United Contractors, Inc. and S & G Prestress Company are attached.

Estimated Budget

The estimated budget for this research project is shown as attached.

DIVISION 1
INTRODUCTION AND GUIDELINES FOR SCC APPLICABILITY

1.1 Introduction

There has not been a recent topic in the concrete industry that has gained as much attention as Self-Consolidating Concrete (5CC). Is this a new building material or an extension of our existing concrete technology? What are the economics and advantages to the Precast/Prestressed producer? Is 5CC for every producer? What levels of technology and skill are required to produce consistent quality SCC?

What is Self-Consolidating Concrete (See)? One definition is given below.

> "A highly flowable, yet stable concrete that can spread readily into place and fill the formwork without any consolidation and without undergoing significant separation."
>
> *Khayat, Hu and Monty*

In 1983, finding sufficiently skilled workers in Japan who could construct durable concrete structures became an industrywide problem. One solution proposed was to develop concrete that would consolidate under its own weight and not require additional vibration or skilled workmen to fully consolidate the plastic concrete. Professor Hajime Okamura (University of Tokyo, now Kochi Institute of Technology) originally advocated 5CC in February the first success with the material was in 1988.

The ability of concrete to flow around and through reinforcing under only the energy of its own weight (without vibration) without creating blockage is referred to as the passing ability of the mix. This capability, in conjunction with the absence of the noise associated with vibration within a precast/prestressed concrete plant, creates a new atmosphere of production opportunities.

SCC is a high-performance concrete in the plastic state. It takes less energy to move the material (lower shear stress) (viscosity) and should not separate or segregate. A material that takes less energy to move will require fewer workers or finishers to produce a quality precast/prestressed unit. 5CC has the potential to allow reallocation of manpower and increased production with existing resources.

When SCC is placed in a form, its motion may be a creeping movement or a rapid flow. Because of this style of flow, the surface finish between the form and the concrete can be exceptionally smooth, creating a much-improved form finish over conventional concrete. To take advantage of the properties of SCC, new production considerations come into play. For example, an important factor in capturing the finish advantages is the type of form oil used, as this can significantly impact the surface finish.

Demanding form configurations, irregular shapes, thin sections, and heavily reinforced elements can be produced with confidence using SCC. Producing concrete without vibration results in a greatly improved work environment in the plant. Safety hazards are also reduced in the plant, as use of SCC minimizes the need for workmen to walk on the top of the form, and eliminates the cords and hoses associated with concrete vibrators. It has been reported that worker absenteeism and accidents have both seen significant reductions when SCC has been introduced into precast production activities.

Concrete forms also benefit from lack of vibration with increased life cycle. Typically form vibration is one of the elements that leads to form damage, associated repair requirements, and ultimately to form replacement.

1.2 Product Applicability

What is the applicability of 5CC? Where can it be used?

Technically, SCC has many advantages over normal production concrete used in precast/prestressed concrete plants. It is well-suited for producing both vertical and horizontal components with block-outs and crowded reinforcing. 5CC is applicable for production of architectural and textured surfaces. Some precast plants are reporting using SCC in nearly 100 percent of their production and expect further opportunities for 5CC with the industry acceptance of an SCC specification.

SCC will require a higher level of quality control, a greater awareness of aggregate gradation, mix water control, and the use of highly advanced high range water reducing admixtures and/or viscosity modifiers.

When looking at SCC costs and benefits versus those of conventional concrete, economic analysis should not be restricted to the material cost of the mix alone. The benefits of 5CC will filter throughout a plant with savings in production labor, greater form life, fewer bug holes, less patching, improved work environment and the opportunity of changing production methods by eliminating vibration. Using SCC in plant production provides the opportunity for improved, more efficient operational procedures. An economic study of SCC use for a specific plant needs to span six months to a year to completely analyze the beneficial impact of 5CC production, as modified production methods associated with the use of the material will continue to evolve over time.

1.3 Changing Production Methods to Take Advantage of SOC Properties

It is expected that significant additional advantages will result from 5CC usage as individual producers rethink their production methods in the context of the characteristics of SCC. For example, can the current methods of concrete transportation within the plant be changed to take advantage of the case of placing SCC? Can the methods of forniing and securing internal reinforcement and hardware be revised because they do not have to withstand the forces associated with the vibration/consolidation process?

Can the time associated with concrete placement be reduced, thus allowing more time in the daily cycle for other things? Can more time be made available for curing during the daily production cycle, thus reducing the need for accelerated curing? Are there elements of the current plant layout that the use of SCC will allow to be made more efficient? Can labor be allocated from placement activities to other important activities allowing improvements in efficiency and quality?

1.4 Potential New Product Applications for Elements Cast from SCC

An important aspect of the design of many current precast elements is the ability to place and consolidate concrete within the form and around the internal reinforcing, prestressing strand, and hardware that are incorporated within the element. In some cases, this includes providing space for the insertion of internal vibrators and assurance that there is sufficient space to allow concrete flow. Can the increased flowability of SCC ease any of these constructabiity requirements and can element shapes be changed to advantage (made more efficient) as a result?

Can smaller diameter reinforcing on smaller grid spacing be used to advantage to develop thinner sections that still provide adequate strength and serviceability? Can high-strength composite materials be used in combination with thinner sections to produce high-value products that are now produced by other segments of industry? SCC may allow the development of new manufacturing processes that can be used to produce new classes of precast concrete elements.